Available online at www.sciencedirect.com

ScienceDirect

Procedia Chemistry 1 (2009) 800–803

Procedia Chemistry

www.elsevier.com/locate/procedia

Proceedings of the Eurosensors XXIII conference

DRIE based technology for 3D silicon barcodes fabrication

R. Gómez-Martínez, A. Sánchez, M. Duch, J. Esteve, J.A.Plaza*

Instituto de Microelectrónica de Barcelona IMB-CNM (CSIC), Cerdanyola, 08193, Barcelona, Spain.
Tel: +34 93 594 77 00, Fax +34 93 580 14 96:

Abstract

Barcoding the microworld has become a promising tool for Cell Biology. Individual and subpopulation cell tracking is of great interest to evaluate cell behavior. Nowadays, many micrometer and even nanometer size silicon 3D structures can be fabricated using microelectronics techniques, i.e., Deep Reactive Ion Etching (DRIE). 3D barcodes reading are less sensitive to the spatial orientation of the code respect to the reader. Therefore, the motivation of this work is to produce small biocompatible barcodes for cell studies that could be freely programmed by controlling the DRIE process parameters.

Keywords: silicon, DRIE, barcodes, cell biology

1. Introduction

Novel barcoding methods and structures at the microworld are presently being developed to label and track small items [1]. In the last decade, individual and subpopulation cell tracking, in order to evaluate cell behavior under different conditions, has become a crucial area in life sciences. Encoded particles from different materials and patterns have been proposed to follow up cells in culture [2]. Many of them require to be read by fluorescence microscopes. However, non florescence light microscopes are the most well-used research tool in cell biology. Compared to 2D barcodes, 3D barcodes reading are less sensitive to the spatial orientation of the code in respect to the reader. So, there is a real necessity of produce 3D small barcodes for single living cell tracking on optical microscopes. These codes have to fulfill special biological, optical and fabrication requirements. They must be designed to the micrometer size as they have to be internalized inside cells. Furthermore, the devices have to be made of a biocompatible material in order to do not affect cell viability. In addition, the codes have to be simple and visible on light microscopes. Thus, the structures that represent every single bit have to be larger than the resolution limit of these microscopes (small features ~1μm). Finally, the fabrication technology has to be able to mass produce reproducible codes, at low-cost, smaller than living cells and with small visible features (bits).

Silicon microtechnologies, used for MEMS and NEMS fabrication, can fulfill these requirements and produce these devices. Nowadays, silicon-based MEMS technologies allow to fabricate small 3D structures. Many micrometer and even nanometer size structures can be fabricated using Deep Reactive Ion Etching (DRIE) equipments [3]. In addition, the etch profiles of these structures can easily be set by changing the etching conditions. Significantly, silicon has been demonstrated to show extracellular biocompatibility [4]. Therefore, the motivation of this work is to produce small biocompatible barcodes that could be freely programmed by using DRIE processes and controlling the etching conditions.

2. 3D barcode design

The proposed 3 D barcodes have a cylindrical shape, Fig. 1.a). Its symbology includes the start marker and the encoding of the single digits of the message. The start marker is an asymmetric structure that helps to the reader to allow the correct reading of data, dark grey structure in Fig. 1.a). The digits are small stacked structures centered on the start marker, Fig. b). The bits have just two possible values (0 or 1). The two different values are represented by a uniform cross-section cylinder (Bit 1) and a non-uniform cross-section cylinder (Bit 0), Fig. 1.c). The data capacity of a barcode, number of possible difference codes, depends on the number of bits, which it is equivalent to the number of stacked cylindrical structures. As already mentioned, the barcode dimensions have to fulfill requirements in terms of cell biology and visibility. Considering the code visibility and their

doi:10.1016/j.proche.2009.07.199

intracellular application, the dimensions of a single bit were fixed to 3 µm x 3 µm. Fig. 1.d) shows an example of a 6 bits code. The illustrated binary code is *011001* that in decimal correspond to the number 25.

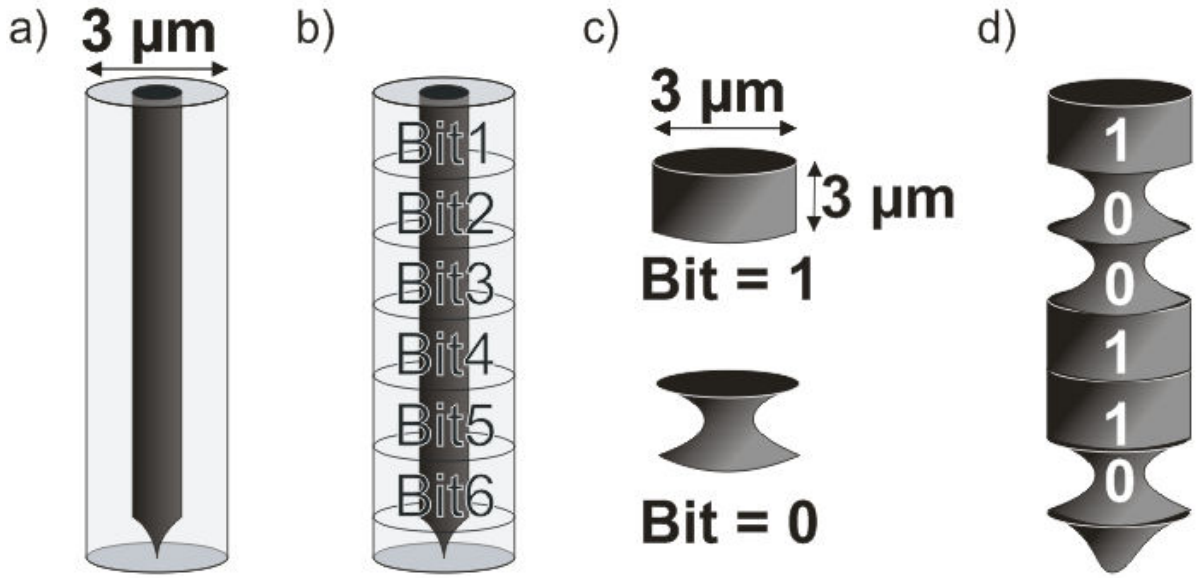

Fig. 1. Schematic view of the barcode design: (a) start marker; (b) start marker and bits localization; c) Bit=1 and Bit=0 representations; d) 3D representation of the code *011001*.

3. DRIE assisted fabrication technology

The proposed technology is based on silicon micromachining in order to obtain micrometer-sized structures with well-controlled geometries, robustness and at low cost (mass production). The key of the technology is that the code number is not defined by a photolithographic step. The same mask with 3 µm spots is always used. Therefore, the codes are defined by sequential dry etching processes. A vertical etch profile define a Bit=1 and a non-vertical etch profile define a Bit=0.

Next, the technology for the fabrication of these barcodes is presented in Fig. 2. First, a silicon wafer is used as substrate, Fig. 2(a). We have chosen silicon because it has been demonstrated to be biocompatible. A silicon oxide layer is deposited and a photolithographic step is done, Fig. 2(b). Then, the silicon oxide layer is patterned, by a dry etching as mask material for the DRIE, Fig. 2(c). Then, by simple varying the etching conditions, such us vertical or non-vertical etch profiles, the researcher can freely program the codes along the axis. For instance, Bit=1 are obtained by a vertical profile etching, Fig. 2(d). Bit=0 require a non-vertical profile etching in combination with a preceding 300 Å thick silicon oxidation in order to protect the bits already done, Fig. 2(e). If the protection layer is not used the previous bits would be destroyed. By combining these two sequences any code can be made. Code *1001* is shown in Fig. (f) as an example. When the codes are finished the chips can be released by a large non-vertical etching. This last process defines a conical structure at the end of the code that can be used as start marker to indicate its correct readout, Fig. 2(g).

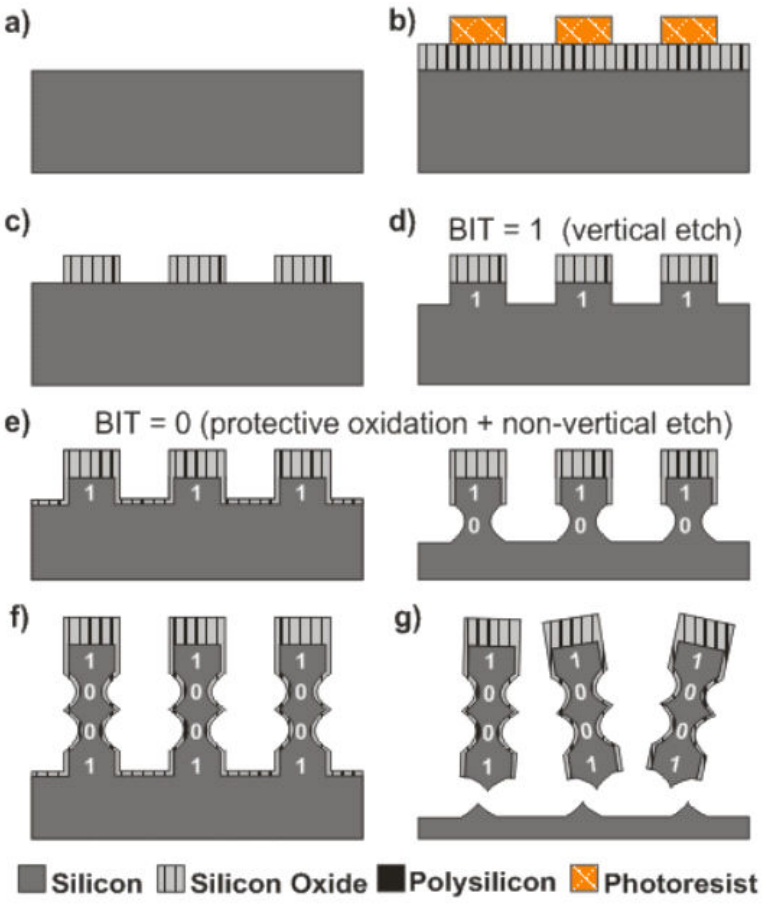

Fig. 2. Example of the fabrication process for the code *1001*: (a) silicon wafer as a substrate; (b) silicon oxide deposition and photolithographic process; (c) silicon oxide patterning; (d) silicon DRIE with vertical profile, Bit=1 ; (e) oxidation and silicon DRIE with non-vertical profile, Bit=0; f) final barcode; g) barcode released.

Fig. 3 shows SEM images of the first bit of a barcode. In a), it is shown a structure with non-uniform section that represents Bit=0 and in b), it is shown a structure with a uniform section that represents Bit=1. A SEM image of several barcodes after release is shown in Fig.4.

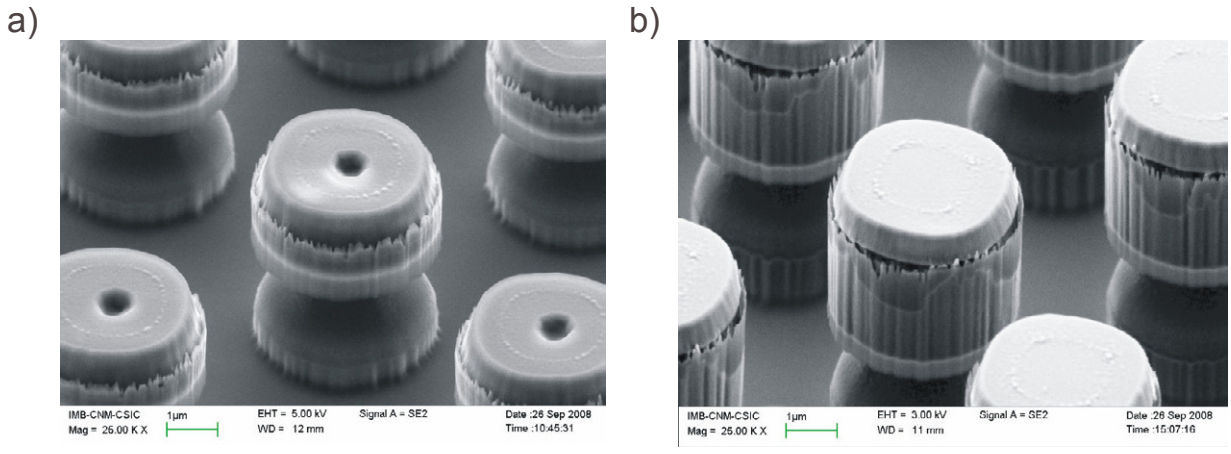

Fig. 3. SEM images of a barcode with one bit fabricated, a) Bit1=0 and b) Bit1= 1.

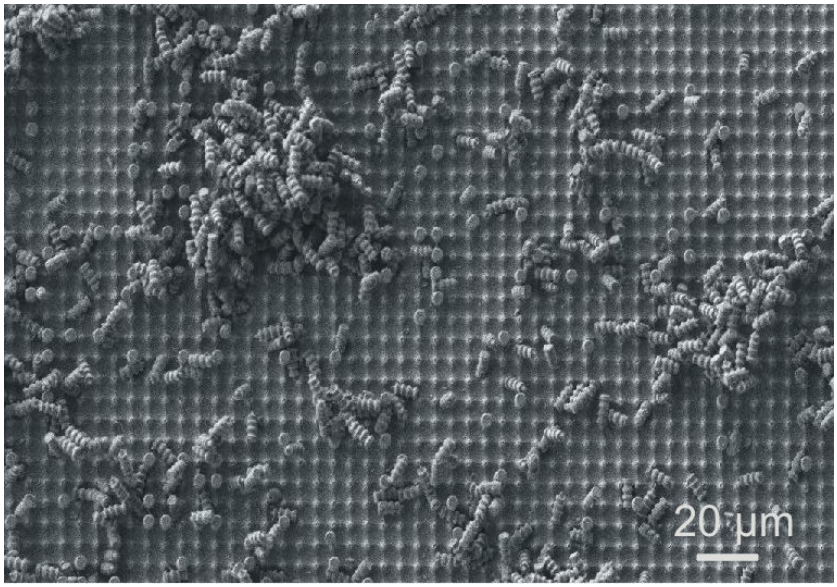

Fig. 4. SEM images of fabricated barcodes after device release.

4. Conclusion and discussion.

Summarizing, biocompatible silicon barcodes have been fabricated and programmed by a sequence of DRIE processes. The main advantages of the proposed codes are: well-controlled shape and dimensions, reproducibility, robustness, large enough to allow their readout by light microscopes and small enough to be internalized inside living cells (biological test are not presented in this paper). In addition, this technology would offer the possibility of thousand of millions of identically barcodes on a 4“ wafer.

Acknowledgements

This study was financed by the Spanish government through the MINAHE 2 project MEC-TEC2005-07996-CO2-01 and MINAHE 3 project MEC-TEC2008-06883-CO3-01. We also wish to thank the IMB-CNM clean room staff.

References

1. Nancy H. Finkel,et a., Barcoding the Microworld. *Anal. Chem*. 2004;**76(19)**:352A–359A.

2. Oren Beske et al. A Novel Encoded Particle Technology that Enables Simultaneous Interrogation of Multiple Cell Types. *J Biomol ecular Screening* 2004*;* **9:**173.

3. G. Villanueva, et al. DRIE based novel technique for AFM probes fabrication. *Microelectronics Engineering* 2007; **84 (5-8)**:1132-1135.

4. Ennio Tasciotti, et al. Mesoporous silicon particles as a multistage delivery system for imaging and therapeutic applications. *Nature Nanotechnology* 2008; **3:**151–157.